SPECIFICATION
TITLE OF THE INVENTION
RADIO COMMUNICATION APPARATUS
BACKGROUND OF THE INVENTION

5   This invention relates to a radio communication apparatus and, more particularly, to a radio communication apparatus in a radio packet communication system for feeding back radio link quality information, which has been measured on a packet receiving side, to

10   a transmitting side and adaptively controlling the modulation scheme and/or encoding rate on the transmitting side using the quality information.

In a radio packet communication system that uses adaptive modulation/demodulation and adaptive encoding

15   such as High-Speed Downlink Packet Access (HSDPA) or High Data Rate (HDR), reception quality is measured from an already known downlink pilot symbol and is reported to the base station. On the basis of the reported value, the base station changes the encoding

20   rate and modulation scheme (a combination of encoding rate and modulation scheme shall be referred to below as a modulation and coding scheme, or "MCS") and then transmits the downlink packet, thereby improving throughput. If the MCS increases, the size of the

25   information data transmitted increases but, on the other hand, so does the reception error rate. From the standpoint of throughput that takes retransmission control into consideration, use is made of adaptive MCS that conforms to reception quality. Further, the

30   general practice is to implement ARQ (Automatic Repeat Request) by applying error detection encoding such as a CRC (Cyclic Redundancy Check) to a transmit packet, detecting reception error at the mobile station and feeding back the result to the base station as an ACK

35   (Acknowledge) signal. Further, since the maximum number of data items transmitted simultaneously to a plurality of mobile stations is limited at the base station, a function for allocating transmission opportunity periodically to the transmit data of a

40   specific one or a plurality of mobile stations becomes necessary. This function is referred to as "scheduling".

A prior-art scheme relating to MCS selection involves exercising control in such a manner that the

reception error rate of a mobile station is rendered
constant. In regard to this prior art, two cases are
conceivable, namely one where control is performed by
the mobile station [see Michiharu Nakamura, Yassin Awad,
Sunil Vadgama, "Adaptive Control of Link Adaptation for
High-Speed Downlink Packet Access (HSDPA) in W-CDMA",
WPMC'02, Oct. 2002] and one where control is performed
by the base station [Toshiyuki Uehara, Makis Kasapidis,
Katsuhiko Hiramatsu and Osamu Katoh, "One Study
Relating to a Transmission Rate Allocation Method in
HSDPA Base Stations", Technical Report of IEICE,
SST2001-77, A·P2001-225, RCS2001-260 MoMuC2001-57,
MW2001-195 (2002-03)]. In a case where control is
performed by the mobile station, error detection is
carried out using CRC or the like and control exercised
so as to lower the reported reception quality if an
error is detected and raise the reported reception
quality if an error is not detected, whereby the
reception error rate converges to a constant value. In
a case where control is performed by the base station,
on the other hand, the ACK signal fed back by the
mobile station is discriminated and control is
exercised so as to enlarge the transmit MCS (enlarge
the data size of the transmit information) in case of
ACK and diminish the transmit MCS (reduce the data size
of the transmit information) in case of NACK, whereby
the reception error rate converges to a constant value.
A stabilized packet error rate characteristic is
obtained as a result. In addition, by setting a target
error rate beforehand so as to maximize throughput, it
is possible to stabilize and improve throughput.

Fig. 11 is a block diagram of a conventional radio
packet communication system in which a base station
adaptively controls a modulation scheme and/or encoding
rate based upon a target error rate as well as radio
downlink quality information and mobile-station
reception success/failure information received from a
mobile station.

A mobile station 1 has a receiver 1a for receiving
a high-frequency signal sent to it from a radio base
station 2, converting the signal to a baseband signal
and inputting the baseband signal to a packet receiver
1b and pilot-symbol receiver 1c. The packet receiver
1b demodulates encoded packet data, applies decode

processing and inputs the decoded signal to an error detector 1d. The latter performs error detection using an error detecting code (CRC code) contained in the decoded signal and inputs the result of detection to an uplink signal generating unit 1e. Meanwhile, the pilot-symbol receiver 1c extracts a pilot symbol and inputs the symbol to a reception quality measurement unit 1f. The latter measures the SIR (Signal to Interference Ratio) as the reception quality of the radio downlink using a known pilot symbol and the received pilot symbol, converts the measured SIR as indicated by Equation (1) below and inputs the result of the conversion to the uplink signal generating unit 1e as downlink reception quality information [referred to below as "CQI" (Channel Quality Indicator)].

$$CQI = f(SIR) = [10 \times \log_{10}(SIR) + C] \qquad (1)$$

where C represents a fixed value given in advance and [X] the largest integer that will not exceed X.

The uplink signal generating unit 1e incorporates ACK/NACK, which is the result of error detection, and the downlink reception quality information CQI in the uplink signal, and a transmitter 1g subjects the uplink signal to modulation processing and frequency conversion and transmits the resultant signal. Fig. 12 illustrates an example of a data format for transmitting ACK/NACK and CQI on an uplink HS-DPCCH channel in 3GPP.

The base station 2 has a receiver 2a for receiving uplink signals from a plurality of mobile stations 1, applying a frequency conversion and demodulation processing to the receive signal and then separating ACK/NACK and CQI from the signal and outputting the same. The base station 2 has a scheduler 2b which, on the basis of the quality information CQI from each mobile station, selects the mobile station to which the next packet is to be transmitted and inputs this information to an MCS decision unit 2c and transmit-data buffer 2d. Conventional examples of schemes for selecting a mobile station that is to be the destination of a transmission include a scheme (Max CIR scheme) for selecting the mobile station that has the best reception quality at that moment, and a scheme (Proportional Fairness scheme) for selecting the mobile station having the largest ratio of momentary reception

quality to average reception quality.

Next, using a CQI - MCS conversion table, the MCS
decision unit 2c decides the MCS (modulation scheme and
encoding rate) of the packet to be transmitted to the
mobile station that has been selected by the scheduler
2b. It should be noted that the MCS decision unit 2c
decides MCS upon referring to the conversion table
after an offset, which is decided by ACK/NACK and the
target error rate, is added to the received CQI. The
offset decided by ACK/NACK and the target error rate is
added on because there is only one conversion table and
it is necessary to apply a correction so as to obtain a
CQI value that conforms to the communication
environment. In this case, if the value of the offset
is updated in accordance with Equation (2) below based
upon ACK/NACK of the mobile station, the reception
quality of mobile station 1 can be made to converge to
a target error rate (PER).

$$\begin{cases} \text{Offset} = \text{Offset} + \alpha \text{ if ACK is received} \\ \\ \text{Offset} = \text{Offset} - \beta \text{ if NACK is received} \end{cases} \tag{2}$$

where α and β are related as follows: $\alpha/\beta = \text{PER}/(1-\text{PER})$.
For example, assume that the target error rate (PER) is
10^{-1} and that $\alpha = 0.1$, $\beta = 0.9$ hold. If the error rate
attains the target error rate (PER) in this case, ACK
is received nine times out of ten and the offset is
increased by a total of 0.9, NACK is received one time
out of ten and the offset is decreased by 0.9, and the
overall increase/decrease in the offset is zero,
whereby convergence to a constant value is achieved.
The reception quality CQI converges to a value
conforming to the target error rate (PER). The MCS
decision unit 2c decides and outputs the MCS
corresponding to the CQI that conforms to the
communication environment and target error rate.

It should be noted that an offset is retained
separately for each mobile station and that offset
updating is performed at the timing at which ACK/NACK
is received even with regard to mobile stations other
than the mobile station that has been selected by
scheduling.

If the mobile station that is to transmit
information and the MCS (modulation scheme and encoding

rate) of each mobile station have thus been decided, the transmit data buffer 2d sends the decided transmit-information data of the mobile station to a transmit packet generator 2e in a size (= TBS) decided by the

5   MCS. The transmit packet generator 2e has the structure shown in Fig. 13. Specifically, a channel encoder 2e-1 encodes the transmit data based upon an encoding rate
(= TBS/n) using the transmit-data bit count (= TBS) and

10   transmit-code bit count (= n) decided by the MCS decision unit 2c, and a modulator 2e-2 creates a downlink radio packet by performing digital modulation in accordance with the modulation scheme (QPSK/16-QAM) similarly decided by the MCS decision unit 2c. A

15   transmitter 2f transmits this radio packet and a known pilot, which enters from a pilot generator (not shown).
    It should be noted that in the case of CDMA, the downlink radio packet transmitted to each mobile station is spread by a channelization code conforming

20   to the mobile station, after which the packet is combined and input to the transmitter 2f. Further, in a case where the packet is transmitted upon application of frequency multiplexing, the data is converted to frequency data conforming to the mobile station and

25   then the frequency data is multiplexed and transmitted. A case where the transmit-code bit count (= n) is input to the transmit packet generator 2e has been described above. However, it can be so arranged that the encoding rate r is calculated by the MCS decision unit

30   2c and input to the transmit packet generator 2e.
    A radio packet transmitted from the mobile station 2 has been encoded to make error detection possible. The mobile station 1 feeds back an ACK symbol if an error has not been detected and a NACK symbol if an

35   error has been detected. Further, the mobile station 1 measures the SIR based upon the pilot symbol, calculates the CQI and feeds it back to the base station. The prior-art communication system for radio packets achieves high-speed packet communication by

40   repeating the above operation.
    Fig. 14 is a block diagram of the MCS decision unit 2c. Specifically, an offset calculating unit 2c-1 calculates the offset for every mobile station according to Equation (2) based upon ACK/NACK, holds

the offset and inputs it to a CQI correction unit 2c-2. The latter adds the offset to the reception CQI to thereby correct the CQI. In case of CDMA, a table 2c-3 stores transport block sizes TBS, code counts Ncode and modulation schemes (QPSK/16-QAM) in association with respective ones of CQIs, as shown in Fig. 15, and outputs a TBS, Ncode and modulation scheme that conform to the entered CQI. It should be noted that the smaller the CQI, i.e., the poorer the downlink reception quality, the smaller the transport block size TBS, the smaller the number of codes multiplexed and, moreover, the smaller the number of data items sent by a single modulation operation. As a result, the target error rate can be met even if the reception quality of the radio downlink varies.

A transmit-code bit count calculating unit 2c-4 calculates the transmit-code bit count n, in a manner described below, using Ncode and the modulation scheme, and outputs n. Specifically, since packet length Nchip is such that Nchip = 7680 [chips] = 0.2 ms holds and spreading factor SF is fixed at SF = 16 [chips], the number M of bits that can be transmitted per packet is as follows:

In case of QPSK: Mbit = Nchip/SF × 2 = 960 bits

In case of 16-QAM: Mbit = Nchip/SF × 4 = 1920 bits
As a result, the transmit-code bit count n is given by the following:

$$n = M \times Ncode \qquad\qquad (3)$$
The transmit-code bit count calculating unit 2c-4 calculates the transmit-code bit count n in accordance with the above equation and outputs n. By way of example, if CQI = 1 holds, then the transmit-code bit count n is equal to 960 × 1. It should be noted that it is also possible to calculate the encoding rate r in accordance with the following equation:

$$r = TBS/(M \times Ncode) \qquad\qquad (4)$$
and output the encoding rate r instead of the transmit-code bit count n. If CQI = 1 holds, then the encoding rate r is equal to 137(960 × 1) = 0.14.

Fig. 16 is a block diagram of another example of a conventional radio packet communication system in which components identical with those shown in Fig. 11 are designated by like reference characters. This example

differs in that the mobile station 1 is provided with a reception-quality report value controller 1h. The latter corrects the offset based upon Equation (2) depending upon whether or not an error has been detected, corrects the reception quality information CQI, which enters from the reception quality measurement unit 1f, using the corrected offset, and transmits the corrected CQI and the ACK/NACK information to the base station 2 in accordance with the format of Fig. 12. The base station 2 performs retransmission control using the ACK/NACK information.

Fig. 17 is a timing chart of a radio packet communication system. Here one slot is defined as the reception quality measurement time, CQI transmit/receive time and packet transmit/receive time at the mobile station 1. The time interval from the moment the mobile station 1 measures reception quality at a certain timing and transmits the CQI to the moment the mobile station 1 transmits the CQI next shall be referred to as a CQI feedback cycle Tcycle. Further, the time interval from the moment the mobile station 1 measures reception quality to the moment a packet that reflects the result of measurement is actually received shall be referred to as the CQI delay time. The shortest CQI delay time shall be referred to as minimum CQI delay time Tmin, and the longest CQI delay time shall be referred to as maximum CQI delay time Tmax. In the timing chart of Fig. 17, the interval from reception quality measurement #0 to reception quality measurement #1 is Tcycle (= 6 slots), the interval from reception quality measurement #0 to packet reception #00 is Tmin (= 3 slots), and the interval from reception quality measurement #0 to packet reception #05 is Tmax (= 8 slots). These values are values given beforehand from a higher order layer.

The target error rate that maximizes throughput differs depending upon the status of the mobile station. For example, the optimum target error rate in a case where throughput has been optimized under conditions where reception quality does not fluctuate from the moment the mobile station measures reception quality to the moment a packet is actually received differs greatly from a case where throughput has been optimized under conditions where reception quality fluctuates

significantly owing to high-speed travel of the mobile
station or a reception-quality reporting period that is
too long. In the prior art, therefore, a problem which
arises is that throughput declines under conditions
5   where a target error rate set in advance is not always
the optimum target error rate. For example, the prior
art is such that if the fading frequency rises, errors
increase and the offset becomes negative in accordance
with Equation (2). As a result, the CQI for satisfying
10   the target error rate decreases. This leads to a
decrease in transmit data quantity and a decline in
throughput.

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is
15   to prevent a decline in throughput even under
conditions where reception quality fluctuates widely
owing to high-speed travel of a mobile station or a
reception-quality reporting period that is too long.

Another object of the present invention is to
20   prevent a decline in throughput by varying the target
error rate in dependence upon the state of
communication of a mobile station.

According to the present invention, the foregoing
object is attained by providing a radio communication
25   apparatus in a radio packet communication system for
feeding back radio link quality information, which has
been measured on a packet receiving side, to a
transmitting side and adaptively controlling a
modulation scheme and/or encoding rate on the
30   transmitting side using the quality information.

According to a first aspect of the present
invention, the radio communication apparatus comprises
means for estimating a variation-with-time
characteristic of the radio link quality using the
35   radio link quality information reported by the packet
receiving side; means for adaptively changing over a
target error rate using the variation-with-time
characteristic; means for deciding a modulation scheme
and/or encoding rate, in such a manner that packet
40   error rate becomes equal to the target error rate,
using the radio link quality information as well as
reception success/failure information reported by the
packet receiving side; and means for transmitting a

packet based upon the modulation scheme and/or encoding rate decided.

According to a second aspect of the present invention, the radio communication apparatus comprises means for estimating a variation-with-time characteristic of the radio link quality using a pilot symbol received from the packet receiving side; means for adaptively changing over a target error rate using the variation-with-time characteristic; means for deciding a modulation scheme and/or encoding rate, in such a manner that packet error rate becomes equal to the target error rate, using the radio link quality information as well as reception success/failure information reported by the packet receiving side; and means for transmitting a packet based upon the modulation scheme and/or encoding rate decided.

In the first and second aspects of the present invention, the means for adaptively changing over the target error rate has a correspondence table indicating correspondence between the variation-with-time characteristic and target error rate, wherein the target error rate is changed over adaptively based upon the variation-with-time characteristic using the table. Further, in the first and second aspects of the present invention, the deciding means tabulates data related to modulation scheme and/or encoding rate in correspondence with the radio link quality information, corrects the radio link quality information by increasing or decreasing it based upon reception success/failure by an amount that conforms to the target error rate, and obtains data related to modulation scheme and/or encoding rate conforming to the radio link quality information after the correction thereof.

According to a third aspect of the present invention, the radio communication apparatus comprises means for estimating throughput on the packet receiving side; means for adaptively controlling a target error rate so as to maximize the throughput; means for deciding a modulation scheme and/or encoding rate, in such a manner that packet error rate becomes equal to the target error rate, using the radio link quality information as well as reception success/failure information reported by the packet receiving side; and

means for transmitting a packet based upon the
modulation scheme and/or encoding rate decided.

According to a fourth aspect of the present
invention, the radio communication apparatus comprises
means for estimating a variation-with-time
characteristic of the radio link quality using a pilot
symbol received from the packet transmitting side;
means for adaptively changing over a target error rate
using the variation-with-time characteristic; means for
receiving a radio packet, which has undergone error
detection and encoding, and performing error detection;
means for measuring a radio link quality value using
the pilot symbol received; means for correcting the
radio link quality value using result of error
detection in such a manner that error rate of the pilot
becomes equal to the target error rate; and means for
reporting the corrected radio link quality value to a
packet transmitting side.

In the fourth aspect of the present invention, the
means for adaptively changing over the target error
rate has a correspondence table indicating
correspondence between the variation-with-time
characteristic and target error rate, wherein the
target error rate is changed over adaptively based upon
the variation-with-time characteristic using the table.

According to a fifth aspect of the present
invention, the radio communication apparatus comprises
means for measuring throughput of a received radio
packet; means for adaptively controlling a target error
rate so as to maximize the throughput; means for
receiving a radio packet, which has undergone error
detection and encoding, and performing error detection;
means for measuring radio link quality value; means for
correcting the radio link quality value using result of
error detection in such a manner that packet error rate
becomes equal to the target error rate; and means for
reporting the corrected radio link quality value to a
packet transmitting side.

In the fourth and fifth aspects of the present
invention, the transmitting side has means for deciding
a modulation scheme and/or encoding rate using the
radio link quality value reported, and means for
transmitting a packet based upon the modulation scheme
and/or encoding rate decided.

In accordance with the present invention, it is possible to prevent a decline in throughput, by varying the target error rate, even under conditions where reception quality fluctuates widely owing to high-speed travel of a mobile station or a reception-quality reporting period that is too long. That is, in accordance with the present invention, a variation-with-time characteristic of reception quality from the moment a mobile station measures reception quality to the moment a packet is actually received is estimated, and the target error rate is changed over adaptively based upon the variation-with-time characteristic in such a manner that throughput is maximized. As a result, a decline in throughput can be prevented.

In accordance with the present invention, a small target error rate is set if the variation in reception quality is small and a large target error rate is set if the variation in reception quality is large, whereby the target error rate is changed over adaptively. The reason for this is that if the target error rate is enlarged when the variation in reception quality is large, then, even though the error rate may deteriorate somewhat, it becomes possible to enlarge the size of the transmit data correspondingly and, hence, throughput can be improved. It should be noted that since recovery from a degraded packet error rate can be achieved by retransmission control, such degradation is not a major problem. This means that in a case where a plurality of mobile stations that travel at various speeds are present in a radio cell, a major improvement in throughput is achieved in comparison with the prior art.

Other features and advantages of the present invention will be apparent from the following description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram illustrating the configuration of a radio packet communication system according to a first embodiment of the present invention;

Fig. 2 is a diagram illustrating a target error rate setting unit according to the first embodiment;

Fig. 3 is a block diagram illustrating the

configuration of a radio packet communication system according to a second embodiment of the present invention;

Fig. 4 is a diagram illustrating a target error rate setting unit according to the second embodiment;

Fig. 5 is a graph showing curves illustrating the relationship between time correlation values and fading frequency;

Fig. 6 is a block diagram illustrating a target error rate setting unit according to a third embodiment, in which a disparity in CQI feedback period is accommodated;

Fig. 7 is a block diagram illustrating the configuration of a radio packet communication system according to a fourth embodiment of the present invention;

Fig. 8 is a flowchart illustrating control of target error rate using throughput;

Fig. 9 is a block diagram illustrating the configuration of a radio packet communication system according to a fifth embodiment of the present invention;

Fig. 10 is a block diagram illustrating the configuration of a radio packet communication system according to a sixth embodiment of the present invention;

Fig. 11 is a block diagram illustrating the configuration of a radio packet communication system according to the prior art;

Fig. 12 illustrates an example of a data format for transmitting ACK/NACK and CQI on an uplink HS-DPCCH channel in 3GPP according to the prior art;

Fig. 13 is a block diagram of a transmit packet generator according to the prior art;

Fig. 14 is a block diagram of an MCS decision unit according to the prior art;

Fig. 15 is a CQI - MCS conversion table according to the prior art;

Fig. 16 is a block diagram of another example of a radio packet communication system according to the prior art; and

Fig. 17 is a timing chart of a radio packet communication system according to the prior art.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

(A) Overview of the present invention

A first radio communication apparatus according to the present invention estimates a variation-with-time characteristic of radio link quality using radio link quality information reported by a packet receiving side, changes over a target error rate adaptively using the variation-with-time characteristic, decides a modulation scheme and/or encoding rate, in such a manner that packet error rate becomes equal to the target error rate, using the radio link quality information as well as reception success/failure information reported by the packet receiving side, and transmits a packet based upon the modulation scheme and/or encoding rate decided.

A second radio communication apparatus according to the present invention estimates a variation-with-time characteristic of radio link quality using a pilot symbol received from a packet receiving side; changes over a target error rate adaptively using the variation-with-time characteristic, decides a modulation scheme and/or encoding rate, in such a manner that packet error rate becomes equal to the target error rate, using the radio link quality information as well as reception success/failure information reported by the packet receiving side, and transmits a packet based upon the modulation scheme and/or encoding rate decided.

A third radio communication apparatus according to the present invention estimates throughput on a packet receiving side, controls a target error rate adaptively so as to maximize the throughput, decides a modulation scheme and/or encoding rate, in such a manner that packet error rate becomes equal to the target error rate, using the radio link quality information as well as reception success/failure information reported by the packet receiving side, and transmits a packet based upon the modulation scheme and/or encoding rate decided.

A fourth radio communication apparatus according to the present invention estimates a variation-with-time characteristic of radio link quality using a pilot symbol received from a packet transmitting side and changes over a target error rate adaptively using the variation-with-time characteristic. Further, the

apparatus receives a radio packet, which has undergone error detection and encoding, performs error detection, measures a radio link quality value using the pilot symbol received, corrects the radio link quality value
5 using result of error detection in such a manner that error rate of the pilot becomes equal to the target error rate, and reports the corrected radio link quality value to a packet transmitting side. Furthermore, the transmitting side decides the
10 modulation scheme and/or encoding rate using the radio link quality value reported and transmits a packet based upon the modulation scheme and/or encoding rate decided.

A fifth radio communication apparatus according to
15 the present invention measures throughput of a received radio packet and controls a target error rate adaptively so as to maximize the throughput. Further, the apparatus receives a radio packet, which has undergone error detection and encoding, performs error
20 detection and measures radio link quality. Further, the apparatus corrects the radio link quality value using result of error detection in such a manner that error rate of the pilot becomes equal to the target error rate, and reports the corrected radio link
25 quality value to a packet transmitting side. Furthermore, the transmitting side decides the modulation scheme and/or encoding rate using the radio link quality value reported and transmits a packet based upon the modulation scheme and/or encoding rate
30 decided.

In accordance with the first to fifth embodiments, throughput can be improved by varying the target error rate in dependence upon the communication status of a mobile station.
35 (B) First Embodiment

Fig. 1 is a block diagram illustrating the configuration of a radio packet communication system according to a first embodiment of the present invention.
40 As shown in Fig. 1, a mobile station 10 has a receiver 11 for receiving a high-frequency signal sent to it from a radio base station 20, converting the signal to a baseband signal and inputting the baseband signal to a packet receiver 12 and pilot-symbol

receiver 13. The packet receiver 12 demodulates
encoded packet data, applies decode processing and
inputs the decoded signal to an error detector 14. The
latter performs error detection using an error
5   detecting code (CRC code) contained in the decoded
signal and inputs the result of detection to an uplink
signal generating unit 15. Meanwhile, the pilot-symbol
receiver 13 extracts a pilot symbol and inputs the
symbol to a reception quality measurement unit 16. The
10   latter measures the SIR (Signal to Interference Ratio)
as the reception quality of the radio downlink using a
known pilot symbol and the received pilot symbol,
calculates downlink reception quality information CQI
(Channel Quality Indicator) using Equation (1) and
15   inputs CQI to the uplink signal generating unit 15.

        The uplink signal generating unit 15 incorporates
ACK/NACK, which is the result of error detection, and
the downlink reception quality information CQI in the
uplink signal, and a transmitter 17 subjects the uplink
20   signal to modulation processing and frequency
conversion and transmits the resultant signal.

        The base station 20 has a receiver 21 for
receiving uplink signals from a plurality of mobile
stations 10, applying a frequency conversion and
25   demodulation processing to the receive signal and then
separating ACK/NACK and CQI from the signal and
outputting the same. The base station 20 has a
scheduler 22 which, on the basis of the quality
information CQI from each mobile station, selects the
30   mobile station to which the next packet is to be
transmitted and inputs this to an MCS decision unit 23
and transmit-data buffer 24.

        A time correlation calculating unit 25 obtains a
time correlation value R_1 of the downlink reception
35   quality information in accordance with the following
equation:

$$R_1 = \frac{\left\langle f^{-1}(CQI_{n+m}) \times f^{-1}(CQI_n) \right\rangle - \left\langle f^{-1}(CQI_n) \right\rangle^2}{\left\langle f^{-1}(CQI_n)^2 \right\rangle - \left\langle f^{-1}(CQI_n) \right\rangle^2} \quad (5)$$

and inputs the value R_1 to a target error rate setting
unit 26. Here the subscript of CQI represents the slot
40   timing at which reception is performed by the base
station. Further, $f^{-1}(X)$ represents the inverse
function of the conversion function [Equation (1)] used

by the mobile station, and $f^{-1}(CQI) = SIR$ holds.
Further, <X> represents the average of X over time.
Furthermore, m represents the slot interval of the
downlink reception quality information for obtaining
the time correlation value.

The target error rate setting unit 26, which has a
correspondence table indicating the correspondence
between the time correlation value R_1 and target error
rate PER, decides the target error rate PER that
corresponds to the time correlation value R_1 calculated
using the table and inputs PER to the MCS decision unit
23. Fig. 2 is a diagram illustrating the structure of
the target error rate setting unit 26. As shown in Fig.
2, the target error rate setting unit 26 includes a
target error rate decision unit 26a and an R_1 - PER
correspondence table 26b. From the correspondence
table the target error rate decision unit 26a obtains
the target error rate PER that corresponds to time
correlation value R_1 and inputs PER to the MCS decision
unit 23. The R_1 - PER correspondence table 26b is
created in the manner set forth below.

When fading frequency f_D increases, errors
increase, the offset takes on a negative value in
accordance with Equation (2) and CQI for meeting the
target error rate diminishes. As a result, the
transmit data quantity decreases, as should be obvious
from the table of Fig. 15, and throughput declines. In
order to raise throughput, therefore, it will suffice
to decide the R_1 - PER correspondence table 26b in such
a manner that the target error rate PER is increased so
that CQI will not decline even if errors increase. In
other words, the R_1 - PER correspondence table 26b is
decided so as to enlarge the target error rate PER as
the time correlation value R_1 a decreases. If the
table 26b is created in this manner, the target error
rate PER can be decided adaptively in accordance with
the value of the time correlation value R_1 so as to
maximize throughput. It should be noted that although
fading frequency (Hz) is included in the R_1 - PER
correspondence table 26b, it has no relation to the
first embodiment but is used in an embodiment that
follows later.

The MCS decision unit 23, which has a structure
identical with that of the Fig. 14, uses the CQI - MCS

conversion table to decide the MCS (modulation scheme and encoding rate) for every mobile station selected by the scheduler 22 and inputs MCS to a transmit packet generator 27. More specifically, the MCS decision unit

5   23 decides α, β based on the target error rate PER on a per-mobile-station basis, calculates an offset in accordance with Equation (2) based upon ACK/NACK, corrects CQI by adding the offset to the received CQI, and obtains and outputs the transport block size TBS,

10   code count Ncode and modulation scheme (QPSK/16-QAM), which correspond to the corrected CQI, from the conversion table. Further, the MCS decision unit 23 calculates and outputs the transmit-code bit count n in accordance with Equation (3) using Ncode and the

15   modulation scheme. It should be noted that it is also possible to calculate the encoding rate r in accordance with Equation (4) and output the encoding rate r instead of the transmit-code bit count n.

     If the mobile station that is to transmit

20   information and the MCS (modulation scheme and encoding rate) of each mobile station have thus been decided, the transmit data buffer 24 sends the transmit-information data of the mobile station to a transmit packet generator 27 in a size (= TBS) decided by the

25   MCS. The transmit packet generator 27, which has the structure shown in Fig. 13, encodes the transmit data based upon an encoding rate (= TBS/n) using the transmit-data bit count (= TBS) and transmit-code bit count (= n) decided by the MCS decision unit 23, and

30   creates a downlink radio packet by performing digital modulation in accordance with the modulation scheme (QPSK/16-QAM) similarly decided by the MCS decision unit 23. A transmitter 28 transmits this radio packet and a known pilot, which enters from a pilot generator

35   (not shown).

     The first embodiment has been described with regard to a case where the transmit-code bit count (= n) is input to the transmit packet generator 27. However, it can be so arranged that the encoding rate r

40   is calculated by the MCS decision unit 23 and input to the transmit packet generator 27. Further, the first embodiment illustrates a case where the packet transmitting side is a radio base station and the packet receiving side is a radio mobile station.

However, the invention can also be applied to uplink
packet communication. It should be noted that these
points also apply to the embodiments that follow.

In accordance with the first embodiment, a
variation-with-time characteristic of reception quality
from the moment a mobile station measures reception
quality to the moment a packet is actually received
thereby is estimated, and the target error rate is
changed over adaptively based upon the variation-with-
time characteristic in such a manner that throughput is
maximized. As a result, a decline in throughput can be
prevented.

(C)   Second Embodiment

Fig. 3 is a block diagram illustrating the
configuration of a radio packet communication system
according to a second embodiment of the present
invention, in which components identical with those of
the first embodiment are designated by like reference
characters. This embodiment differs only in the method
of calculating the time correlation and the method of
setting the target error rate and is the same as the
first embodiment in other respects.

A time correlation calculating unit 31 obtains a
time correlation value R_2 of the downlink reception
quality information in accordance with the following
equation:

$$R_2 = \frac{\langle \text{Re}[s(t+\tau)^* s(t)] \rangle}{\langle |s(t)|^2 \rangle} \qquad (6)$$

and inputs the value R_2 to a target error rate setting
unit 32. In Equation (6), s(t) represents a complex
uplink pilot symbol that prevails after pilot pattern
cancellation, t a time interval at which the time
correlation is acquired, Re[] a function for taking the
real part of a complex signal, and <X> the average of X
over time.

The target error rate setting unit 32, which has a
correspondence table indicating the correspondence
between the time correlation value R_2 and target error
rate PER, decides the target error rate PER that
corresponds to the calculated time correlation value R_2
using the table and inputs PER to the MCS decision unit
23. Fig. 4 is a diagram illustrating the structure of
the target error rate setting unit 32. As shown in Fig.
4, the target error rate setting unit 32 includes a

target error rate decision unit 32a and an R_2 - PER correspondence table 32b. From the correspondence table the target error rate decision unit 32a obtains the target error rate PER that corresponds to time
5   correlation value R_2 and inputs PER to the MCS decision unit 23. The R_1 - PER correspondence table 32b is created through an approach similar to that of the first embodiment. Specifically, the R_2 - PER correspondence table 32b is decided so as to enlarge
10 the target error rate PER as the time correlation value R_2 a decreases. If the table 32b is created in this manner, the target error rate PER can be decided adaptively in accordance with the value of the time correlation value R_2 so as to maximize throughput. It
15 should be noted that although fading frequency (Hz) is included in the R_2 - PER correspondence table 32b, it has no relation to the second embodiment but is used in an embodiment that follows later.
        Thereafter, in a manner similar to that of the
20 first embodiment, the MCS decision unit 23 inputs the transport block size TBS, the modulation scheme (QPSK/16-QAM) and the transmit-code bit count n or the encoding rate r to the transmit packet generator 27. The latter performs encoding based upon the encoding
25 rate r (= TBS/n) and creates a downlink radio packet by performing digital modulation in accordance with the modulation scheme (QPSK/16-QAM), and the transmitter 28 transmits this radio packet and a known pilot, which enters from a pilot generator (not shown).
30   In case of FDD where the uplink and downlink frequencies differ from each other, the uplink fading environment differs from the downlink fading environment. However, the variation-with-time characteristic on the uplink does not change much from
35 the variation-with-time characteristic on the downlink and the two are considered to be statistically equal. In other words, the uplink reception quality variation characteristic is considered to have a high degree of correlation with the downlink reception quality
40 variation characteristic. In the second embodiment, therefore, the time correlation of the radio downlink is estimated using the uplink pilot symbol to obtain results similar to those of the first embodiment. In the event that there is a large difference between

uplink and downlink frequencies, the table would be created taking this difference into consideration.

(D)   Third Embodiment

In radio communication, signals from a transmitter are reflected, diffracted and scattered by objects in the vicinity of the receiver, resulting in a multiplexed propagation path. A large number of waves that arrive at the vicinity of the receiver from various directions interfere with one another so that a random standing-wave electromagnetic distribution is formed. When a mobile station travels through such an electromagnetic distribution, a phenomenon referred to as fading, in which the amplitude and phase of received waves fluctuate randomly, occurs. In an ideal fading environment, the time correlation values R_1, R_2 in Equations (5), (6) and the fading frequency f_D decided by the travelling speed of the mobile station are related as indicated by the following Equations (7), (8), respectively:

$$R_1 = \{J_0(2\pi f_D\tau)\}^2 \qquad\qquad (7)$$

$$R_2 = J_0(2\pi f_D\tau) \qquad\qquad (8)$$

where f_D represents the fading frequency [Hz], τ the time interval of the correlation, and $J_0(X)$ a Bessel function of degree 0. Accordingly, on the assumption of an ideal fading environment, the fading frequency f_D can be obtained from the time correlation values R_1, R_2. Fig. 5 is a graph showing curves illustrating the relationship between the time correlation values R_1, R_2 and fading frequency f_D in a case where τ = 6 ms holds. The time correlation values R_1, R_2 decrease monotonously in dependence upon the fading frequency f_D until f_D reaches 50 Hz. The fading frequencies f_D indicated in the tables of Figs. 2 and 4 are values calculated in accordance with Equations (7) and (8).

The first and second embodiments relate to a case where the target error rate PER is decided adaptively from the time correlation characteristics R_1, R_2 when the CQI feedback interval is held constant. However, the period at which the radio link quality information CQI is fed back to the transmitting side differs depending upon the mobile station. In such case the relationships between the time correlation characteristics R_1, R_2 and the fading frequency f_D

deviate from those shown in Figs. 2 and 4. Since the relationship between the product of the fading frequency f_D and CQI delay interval and the target error rate PER is invariable, the relationships between the time correlation characteristics R_1, R_2 and the target error rate PER deviate from those shown in Figs. 2 and 4. Here the CQI delay interval is defined as the time interval between measurement of reception quality and receipt of a packet (see Fig. 17).

In view of the foregoing, it is necessary to decide the target error rate so as to accommodate a disparity in the period at which CQI is fed back to the transmitting side, i.e., a disparity in the CQI delay interval.

Fig. 6 is a block diagram illustrating a target error rate setting unit according to a third embodiment, in which a disparity in CQI feedback period is accommodated. This target error rate setting unit can be used instead of the target error rate setting units 26, 32 of the first and second embodiments, respectively.

A first conversion table 41 converts the time correlation characteristic R_1 or R_2 to the fading frequency f_D in a case where the time interval at which the correlation value is calculated is made a constant value (6 ms in this case). The table 41 stores the corresponding relationship between the time correlation characteristic R_1 or R_2 and fading frequency f_D [the corresponding relationship based upon Equations (7), (8)]. A second conversion table 42 converts a variation-with-time coefficient (correction fading frequency) f_D', which is obtained by multiplying the fading frequency f_D by average CQI delay time, to the target error rate PER. The table 42 is created based upon the relationship between the fading frequency f_D and target error rate PER shown in Figs. 2 or 4. An average CQI delay calculation unit 43 outputs the average value of minimum CQI delay time Tmin (see Fig. 17) and maximum CQI delay time Tmax as the average CQI delay time, and a multiplier 44 multiplies the fading frequency f_D by the average CQI delay time and divides the product by the time interval at which the correlation value is calculated. The resultant signal is output as the variation-with-time coefficient f_D'.

The target error rate PER setting unit according to the third embodiment decides the fading frequency f_D using the first conversion table 41 created from the time correlation characteristic R_1 or R_2 using Equation

5 (7) or (8), multiplies the fading frequency by the average CQI delay time and divides the product by the time interval at which the correlation value is calculated, thereby to obtain the variation-with-time coefficient f_D'. The setting unit then decides the

10 target error rate PER using the variation-with-time coefficient f_D' obtained and the predetermined second conversion table 42.

In accordance with the third embodiment, the fading frequency f_D is corrected by multiplying it by

15 the average CQI delay time, which is the average value of the minimum CQI delay time Tmin and maximum CQI delay time Tmax, and the target error rate PER is found from the corrected fading frequency. As a result, the target error rate PER can be decided upon taking into

20 account a disparity in the CQI feedback period and the time interval at which the correlation value is calculated.

(E) Fourth Embodiment

Fig. 7 is a block diagram illustrating the

25 configuration of a radio packet communication system according to a fourth embodiment of the present invention, in which components identical with those of the first embodiment are designated by like reference characters. This embodiment differs in that a

30 throughput measurement / target error rate setting unit 51 instead of the time correlation calculating unit 25 and target error rate setting unit 26.

In the fourth embodiment, the throughput measurement / target error rate setting unit 51

35 measures the throughput of each mobile station 10 and decides the target error rate PER by increasing the target error rate if throughput rises and decreasing the target error rate if throughput falls. In a manner similar to that of the first embodiment, the MCS

40 decision unit 23 thenceforth inputs the transport block size TBS, the modulation scheme (QPSK/16-QAM) and the transmit-code bit count n or the encoding rate r to the transmit packet generator 27. The latter performs encoding based upon the encoding rate r (= TBS/n) and

creates a downlink radio packet by performing digital
modulation in accordance with the modulation scheme
(QPSK/16-QAM), and the transmitter 28 transmits this
radio packet and a known pilot, which enters from a
pilot generator (not shown).

Fig. 8 is a flowchart illustrating control of
target error rate using throughput.

The throughput measurement / target error rate
setting unit 51 increments n (n+1 → n, where the
initial value of n is 0; step 101), acquires from the
MCS decision unit 23 the information data size TBS
(Transport Block Size) of the transmitted data and
calculates the average value <TBS> thereof (step 102).

Next, throughput (which here means an expected
value of information data size capable of being
received with one packet) is found by multiplying the
average value of TBS by a value that is the result of
subtracting the target error rate PER from 1, as
indicated by the following equation (step 103):

$$\text{Throughput} = <TBS>(1-PER) \qquad (9)$$

More specifically, the target error rate PER is held
fixed, TBS is averaged over a fixed time to obtain
throughput throughput(n), then the present throughput
throughput(n) and the preceding throughput
throughput(n-1) are compared in terms of size (step
104). It should be noted that it is assumed that
throughput(0) = 0 holds. If it is determined that
throughput(n) > throughput(n-1) holds, then the target
error rate PER is increased by PERstep (e.g., 0.1) in
accordance with the following equation (step 105):

$$PER = PER + PERstep$$

Next, it is determined whether PER has attained
the maximum value (= PERmax) (step 106) and processing
from step 101 onward is executed if the maximum value
has not been reached. If the maximum value has been
attained, on the other hand, the limitation PER =
PERmax is applied (step 107), after which processing
from step 101 onward is executed. Thus, if throughput
rises, PER is enlarged so as to lower throughput.

If throughput(n) ≤ throughput(n-1) is found to
hold at step 104, then the target error rate PER is
reduced by PERstep (e.g., 0.1) in accordance with the
following equation (step 108):

$$PER = PER - PERstep$$

Next, it is determined whether PER has attained a minimum value (= PERmin) (step 109) and processing from step 101 onward is executed if the minimum value has not been attained. If the minimum value has been attained, on the other hand, the limitation PER = PERmin is applied (step 110), after which processing from step 101 onward is executed. Thus, if throughput falls, PER is reduced so as to raise throughput.

In accordance with the fourth embodiment, TBS is averaged over fixed time intervals to find throughput, this throughput is compared with the immediately preceding throughput, the target PER is incremented by one step if throughput has risen and is decremented by one step if throughput has fallen. As a result, the PER varies between the maximum value (PERmax) and minimum value (PERmin). By repeating this, the target error rate can be made to converge to an area in which throughput is maximized.

(F) Fifth Embodiment

Fig. 9 is a block diagram illustrating the configuration of a radio packet communication system according to a fifth embodiment of the present invention, in which components identical with those of the second embodiment are designated by like reference characters. This embodiment differs in that (1) the time correlation characteristic is calculated by the mobile station 10; (2) the target error rate PER is decided adaptively based upon this time correlation characteristic; (3) the radio downlink quality information CQI is corrected based upon this target error rate PER and the result of error detection; and (4) the quality information CQI is transmitted to the base station 20 and the latter decides the transport block size TBS, the modulation scheme (QPSK/16-QAM) and the transmit-code bit count n or the encoding rate r based upon the quality information CQI.

A time correlation calculating unit 61 calculates the time correlation value R_2 of downlink reception quality in accordance with Equation (6) using the downlink pilot symbol and inputs R_2 to a target error rate setting unit 62.

The target error rate setting unit 62, which has a correspondence table indicating the correspondence between the time correlation value R_2 and target error

rate PER, decides the calculated target error rate PER that corresponds to the time correlation value R_2 using the table and inputs PER to a reception-quality report value controller 63. It should be noted that the target error rate setting unit 62 has a structure identical with that shown in Fig. 4.

The reception-quality report value controller 63 decides α, β based on the target error rate PER, calculates an offset in accordance with Equation (2) based upon the result of error detection and corrects CQI by adding the offset to the CQI output by the reception quality measurement unit 16. The uplink signal generating unit 15 incorporates ACK/NACK, which is the result of error detection, and the corrected reception quality information CQI in the uplink signal, and the transmitter 17 subjects the uplink signal to modulation processing and frequency conversion and transmits the resultant signal.

The receiver 21 of the base station 20 receives uplink signals from a plurality of the mobile stations 10, applies a frequency conversion and demodulation processing to the receive signal and then separates ACK/NACK and CQI from the signal and outputs the same. On the basis of the quality information CQI from each mobile station, the scheduler 22 of the base station selects the mobile station to which the next packet is to be transmitted and inputs this information to the MCS decision unit 23 and transmit-data buffer 24. The MCS decision unit 23 inputs the transport block size TBS, the modulation scheme (QPSK/16-QAM) and the transmit-code bit count n or the encoding rate r, which correspond to the CQI, from the CQI - MCS correspondence table to the transmit packet generator 27. The latter performs encoding based upon the encoding rate
r (= TBS/n) and creates a downlink radio packet by performing digital modulation in accordance with the modulation scheme (QPSK/16-QAM), and the transmitter 28 transmits this radio packet and a known pilot, which enters from a pilot generator (not shown).

In accordance with the fifth embodiment, in a manner similar to that of the first embodiment, a variation-with-time characteristic of reception quality from the moment a mobile station measures reception

quality to the moment a packet is actually received thereby is estimated, and the target error rate is changed over adaptively based upon the variation-with-time characteristic in such a manner that throughput is maximized. As a result, a decline in throughput can be prevented.

Further, the variation-with-time characteristic of downlink reception quality can be calculated accurately by a simple correlation calculation applied to a pilot symbol.

It should be noted that in a case where the CQI reporting period of a mobile station fluctuates, the time correlation value R_2 calculated in accordance with Equation (6) is converted to the fading frequency f_D, the reception quality variation coefficient f_D' is obtained by multiplying the fading frequency f_D by the average CQI delay time, and the target error rate PER is decided using a predetermined table. As a result, even if the CQI reporting period fluctuates for every mobile station, this fluctuation can be accommodated.

(G)   Sixth Embodiment

Fig. 10 is a block diagram illustrating the configuration of a radio packet communication system according to a sixth embodiment of the present invention, in which components identical with those of the fourth embodiment of Fig. 7 are designated by like reference characters. This embodiment differs in that (1) the mobile station 10 is provided with a throughput measurement / target error rate setting unit 71 for deciding the target error rate PER adaptively at the mobile station; (2) a reception-quality report value controller 72 corrects the radio downlink quality information CQI based upon the PER and the result of error detection; and (3) the quality information CQI is transmitted to the base station 20 and the latter decides the transport block size TBS, the modulation scheme (QPSK/16-QAM) and the transmit-code bit count n or the encoding rate r based upon the quality information CQI.

The throughput measurement / target error rate setting unit 71 obtains throughput by averaging TBS at fixed time intervals in accordance with the flowchart of Fig. 8, compares this throughput with the immediately preceding throughput, increments the target

error rate PER by one step if throughput has risen,
decrements the target error rate PER by one step if
throughput has fallen and inputs the target error rate
PER to the reception-quality report value controller 72.

5   The reception-quality report value controller 72
decides α, β based on the target error rate PER,
calculates an offset in accordance with Equation (2)
based upon the result of error detection and corrects
CQI by adding the offset to the CQI output by the

10   reception quality measurement unit 16. The uplink
signal generating unit 15 incorporates ACK/NACK, which
is the result of error detection, and the corrected
reception quality information CQI in the uplink signal,
and the transmitter 17 subjects the uplink signal to

15   modulation processing and frequency conversion and
transmits the resultant signal.
       The receiver 21 of the base station 20 receives
uplink signals from a plurality of the mobile stations
10, applies a frequency conversion and demodulation

20   processing to the receive signal and then separates
ACK/NACK and CQI from the signal and outputs the same.
On the basis of the reception quality information CQI
from each mobile station, the scheduler 22 of the base
station selects the mobile station to which the next

25   packet is to be transmitted and inputs this information
to the MCS decision unit 23 and transmit-data buffer 24.
The MCS decision unit 23 inputs the transport block
size TBS, the modulation scheme (QPSK/16-QAM) and the
transmit-code bit count n or the encoding rate r, which

30   correspond to the CQI, from the CQI - MCS
correspondence table to the transmit packet generator
27. The latter performs encoding based upon the
encoding rate
r (= TBS/n) and creates a downlink radio packet by

35   performing digital modulation in accordance with the
modulation scheme (QPSK/16-QAM), and the transmitter 28
transmits this radio packet and a known pilot, which
enters from a pilot generator (not shown).
       In accordance with the sixth embodiment, effects

40   equivalent to those of the fourth embodiment can be
obtained.
       In the foregoing embodiments, there are portions
that have been described taking into account a case
where communication is performed according to a CDMA

scheme. However, the present invention is not limited to CDMA communication and is applicable to various transmission schemes such as frequency multiplexing and time division multiplexing.

5   Further, in the foregoing embodiments, encoding rate and modulation scheme are controlled based upon reception quality information. However, it may be so arranged that one parameter only is controlled.

      As many apparently widely different embodiments of

10 the present invention can be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited to the specific embodiments thereof except as defined in the appended claims.